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Influence of Family and Nitrogen Fertilizer on Growth and Nutrition of Western Hemlock Seedlings

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Abstract

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Effects of genotype and nitrogen fertilizer on growth and shoot nutrients of western hemlock seedlings were determined by using 11 open-pollinated families from coastal Oregon and Washington. The families differed significantly in growth, initially and after one growing season after treatment. All seedlings responded well to fertilizer, and fertilization significantly affected concentration and content of shoot nutrients. Nutrient levels also differed significantly among families, but there were only few significant family × fertilizer interactions. Results suggest that selections of superior families of western hemlock can be made equally well with or without fertilizer.

Keywords: Family effects, fertilizer effects, family × fertilizer interaction, seedling growth, nutrients, western hemlock.

Summary

Seedlings of 11 open-pollinated families of western hemlock were assessed for growth and shoot nutrients with and without nitrogen (N) fertilizer. Seed parents of the test seedlings are located in coastal Oregon and Washington, from 45.5° to 48.2° N. latitude and at elevations of 46 to 564 meters. Potted 1-year-old seedlings were used. Fertilizer was applied as ammonium nitrate at rates equivalent to 0, 50, and 100 kg N/ha in spring before bud burst. Heights and diameters of the seedlings were measured immediately before fertilizer was applied. Seedlings were harvested after one growing season, and data on height, diameter, dry weights of shoots and roots, and shoot nutrients were collected. The families differed significantly in tree height and stem diameter before the fertilizer was applied. Families 1 and 11 had the tallest seedlings, families 1 and 10 had the largest diameter, and family 9 had the shortest seedlings. The seedlings responded well to the added fertilizer. For all 11 families, the N fertilizer significantly affected all growth parameters measured. The superiority of the fertilized over unfertilized seedlings averaged 36 percent for height growth, 62 percent for diameter growth, and 64 percent for seedling dry weight. Differences in growth between the 50- and the 100-kg-N/ha treatments were not significant. For all fertilization treatments, there were significant differences among families in height, diameter, and dry weights of shoots and roots of the harvested trees. Overall, seedlings of families 1 and 11 seemed superior to those of other families. The N fertilizer significantly affected concentration and content of all macronutrients determined in seedling shoots. Fertilization increased concentration and content of N, and the increases were significantly greater at the higher rate of application. Dilution by growth significantly reduced the concentration but not the content of phosphorus (P), potassium (K), and magnesium (Mg). Concentrations and contents of all nutrients determined differed significantly among families. Over all fertilization treatments, nutrient concentrations in the shoots of the different families ranged from 0.71 to 0.86 percent N, 0.07 to 0.09 percent P, 0.53 to 0.62 percent K, 0.38 to 0.46 percent calcium (Ca), 0.10 to 0.12 percent Mg, and 0.05 to 0.07 percent sulfur (S). Positive and negative correlations were found between growth parameters and shoot nutrients; strongest correlations were with N (positive) and K (negative). There were few significant family × fertilizer interactions. Among all growth characteristics measured, only the final seedling diameter interaction was significant. Also, interactions of shoot nutrients

were limited to N and Mg concentrations and N content. The practical importance of these interactions is not immediately apparent because of the lack of significant interactions in other important growth characteristics, such as height and weight. This suggests that family selections can be made equally well with or without fertilizer. Similar conclusions were previously reached by others for other coniferous tree species.

Contents

Introduction

Differences among genotypes within plant species in growth and uptake of nutrients from native sources or introduced fertilizers have been known and exploited in genetic improvement programs for many years. Such diversity has occurred to varying degrees among some forest tree species (for example, Jahromi and others 1976, Matziris and Zobel 1976, Maliondo and Krause 1985, Rockwood and others 1985).

In the Pacific Northwest, there is some literature on the genetic variation in the two principal tree species in the region, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Work with Douglas-fir has included studies of effects of families and nitrogen (N) fertilizer on growth and foliar nutrients (for example, Bell and others 1979, DeBell and others 1986). Studies on western hemlock, however, have been more limited and confined primarily to variation in some growth characteristics. An example of such work is by Foster and Lester (1983), who reported significant variation in height among 213 open-pollinated families of western hemlock. There is no literature on family × fertilizer interaction in western hemlock.

This paper reports results of a study designed to assess effects of families and nitrogen fertilizer on growth and shoot nutrients of seedlings from 11 open-pollinated western hemlock families.

Materials and Methods

Test Seedlings

Female parents of the 11 test families occur in western Oregon and western Washington at elevations ranging from 46 to 564 m; the trees represented a wide range of ages (43 to 67 years), height (22 to 36 m), and breast-high diameter (33.8 to 46.2 cm) (table 1).

Seeds were collected from the parent trees in fall 1975. Seeds of the different families were individually packed in plastic containers and stored in a freezer until needed.

Table 1—Selected characteristics of the parent trees and their sites

Family	Tree age	Tree height	Tree diameter at breast height	Site elevation	Site location
	Year	*Meters*	*Centimeters*	*Meters*	*County, State*
1	59	28	44.2	46	Clatsop, OR
2	43	23	37.6	427	Clatsop, OR
3	46	22	43.2	396	Clatsop, OR
4	60	34	46.2	91	Tillamook, OR
5	61	36	41.1	91	Tillamook, OR
6	60	35	41.9	107	Tillamook, OR
7	45	31	39.9	408	Wahkiakum, WA
8	50	24	44.7	564	Wahkiakum, WA
9	54	35	42.2	177	Wahkiakum, WA
10	67	34	44.4	122	Clallam, WA
11	47	26	33.8	46	Clallam, WA

In spring 1979, seeds, stratified at 3-5 °C for 3 weeks, were sown at 3-mm depth in styroblock containers filled with 1:1 (v/v) mixture of peat moss and vermiculite. Seeds were covered with a thin layer of silica grit to discourage algal growth, and the containers were kept in a plant growth chamber. The chamber was programmed for alternating diurnal temperatures of 27 °C for 16 hours and 17 °C for 8 hours, with fluorescent-incandescent light available during the period of higher temperature. Water was added as required and after 4 weeks, seedlings were thinned to one per styroblock cavity. Seedlings were then watered with a dilute nutrient solution (Hoagland and Arnon 1950) twice a week, and cavities were flushed with water once a month to prevent accumulation of excess salts. In September, the styroblock containers were moved to a roofed lathhouse, and addition of nutrient solution was discontinued to slow growth and to encourage budset and cold hardiness.

In early spring 1980, seedlings were removed from the styroblocks and were individually planted in 7.6-liter plastic pots with a surface area of 3.0172×10^{-6} ha each. The pots contained Tumwater sandy loam top soil (6 kg/pot). A three-seedling group served as the basic experimental unit. Three groups of three seedlings each (three replicates and nine seedlings) were used for each of three fertilization treatments. Seedlings were placed, as groups of three, at random on wooden benches in the roofed lathhouse.

Fertilization Treatments

There were an untreated control and two nitrogen fertilization treatments. Commercial ammonium nitrate fertilizer (34 percent N) was used. It was chosen over other N fertilizers because we wanted to avoid the appreciable increase in soil pH associated with urea and prevent addition of nutrients other than N which are present as cations or anions in other N fertilizers.

The fertilizer was applied in May 1980 on an area basis at rates equivalent to 0, 50, and 100 kg N/ha. Fertilizer was dissolved in water, and the required amount of solution was added to individual seedlings in the pots. Seedlings were watered the same day the fertilizer was applied and periodically thereafter as required.

Growth Measurements

Height and diameter of the test seedlings were determined before treatment in May and in November when the seedlings were harvested at the end of the experiment. At harvest, shoots and roots were separated by clipping at the root collar. Roots were washed free of soil, and excess moisture was removed with blotting towels. Shoots and roots were cut up and dried to constant weight at 65 °C. Height and diameter growth were calculated, and dry weights of shoots and roots were determined.

Processing of Soils and Shoots

Before the test was started, a representative sample of the study soil was passed through a 2-mm sieve. Sieved soil was used for determination of total sulfur (S), extractable phosphorus (P), cation exchange capacity, and exchangeable potassium (K), calcium (Ca), and magnesium (Mg), and pH. Sieved soil was ground to a fine powder before total N was determined.

Ovendry shoots were ground to 40 mesh in a mill and stored in plastic containers until analyzed.

Chemical Analyses

Soil was characterized by determination of pH on a 1:1 mixture with water by glass electrode, total N by semimicro-Kjeldahl method (Bremner and Mulvaney 1982), total S by turbidimetric method (Butters and Chenery 1959), Bray 2-extractable P according to Bray and Kurtz (1945), cation exchange capacity by NH_4OAc extraction (Chapman and Pratt 1961), and exchangeable K, Ca, and Mg (NH_4OAc extraction) by atomic absorption (Perkin-Elmer Corporation 1976).

Shoots were analyzed for total N and total S, respectively, by the micro-Kjeldahl procedure (Bremner and Mulvaney 1982) and by the turbidimetric method of Butters and Chenery (1959). Other nutrients were determined as follows: P by the molybdenum blue method (Chapman and Pratt 1961), and K, Ca, and Mg by atomic absorption (Perkin-Elmer Corporation 1976).

Statistical Analyses

Effects of family and fertilization on growth variables and shoot nutrients were assessed by analysis of variance, and means were separated by Tukey's test as required (Snedecor 1961). Analysis was based on families as fixed effect, and inference was limited to the 11 families used in the study. Correlation coefficients (r) were also calculated to determine the relationships between growth and site elevation of the parent trees and between growth and shoot nutrients (Snedecor 1961). In all analyses, results were considered significant at $p<0.05$.

Results and Discussion

The Study Soil

The soil was particularly low in total N, total S, and cation exchange capacity (table 2). Soil reaction was moderately acidic, and extractable P was above average. The soil contained sufficient concentrations of exchangeable K, Ca, and Mg.

Family × Fertilizer Interactions

There were few significant family × fertilizer interactions. Among all growth characteristics measured, the interaction was significant only for final seedling diameter. Also, significant interactions for shoot nutrients were limited to N and Mg concentrations and N content. The practical importance of these interactions is not immediately apparent because of the lack of significant interactions in other important growth variables, such as seedling height and weight. This suggests that selections of superior families of western hemlock can be made equally well with or without fertilizer. Lack of genotype × fertilizer interaction of significant importance has also been reported for loblolly pine (*Pinus taeda* L.) (Matziris and Zobel 1976) and Douglas-fir (DeBell and others 1986).

Table 2—Selected characteristics of the study soil

Item	Character/value
Soil parent material	Glacial
pH	5.80
Kjeldahl N (percent)	.07
Total S (percent)	.01
Bray 2-extractable P (p/m)	166.00
Cation exchange capacity (meq/100 g)	8.40
Exchangeable (NH_4OAc) K (meq/100 g)	.35
Exchangeable (NH_4OAc) Ca (meq/100 g)	3.25
Exchangeable (NH_4OAc) Mg (meq/100 g)	.35

Effect of Fertilizer on Seedling Growth

The seedlings responded positively to addition of ammonium nitrate, and seedlings were consistently much larger with than without fertilizer (fig. 1). For all 11 families, the N fertilizer significantly affected all growth variables measured (table 3). The superiority of the fertilized over unfertilized seedlings averaged 36 percent for height growth, 62 percent for diameter growth, and 64 percent for seedling dry weight. Increasing the fertilization rate from 50 to 100 kg N/ha, however, did not result in any further increase in growth. A 50-kg-N/ha application rate, therefore, seems more suitable for pot studies than the conventional 224 kg N/ha normally used in field tests.

Nitrogen fertilizer has not always increased growth of hemlock in pot experiments (for example, Radwan and DeBell 1980) or in the field (for example, Radwan and others 1984). Factors affecting the erratic response of hemlock to N fertilizer are still unknown although slow-release fertilizers seem promising (Radwan and DeBell 1989).

Figure 1—Unfertilized (left) and fertilized (right) western hemlock seedlings of family 10 (July 1980).

Table 3—Effect of nitrogen fertilizer on growth of western hemlock seedlings[a]

Fertilization treatment	Final height	Height growth	Final diameter	Diameter growth	Seedling dry weight
	Centimeters		*Millimeters*		*Grams*
0 kg N/ha	38.8 a	17.6 a	5.7 a	2.0 a	14.8 a
50 kg N/ha	45.5 b	24.2 b	7.0 b	3.1 b	24.3 b
100 kg N/ha	44.6 b	23.4 b	7.1 b	3.2 b	23.5 b

[a] Values are averages of 11 families each, with 3 replications of 3 seedlings each per family. Averages in the same column followed by the same letter are not significantly different at $P<0.05$.

Family Differences In Seedling Growth

Initial height and diameter varied by family (fig. 2). At the time of treatment, height ranged from 18.1 to 24.2 cm, and diameter ranged from 3.65 to 4.06 mm. Families 1 and 11 had the tallest seedlings, and families 1 and 10 had the largest diameter. Family 9 had the shortest seedlings. All seedlings appeared healthy and showed no symptoms of nutrient deficiency.

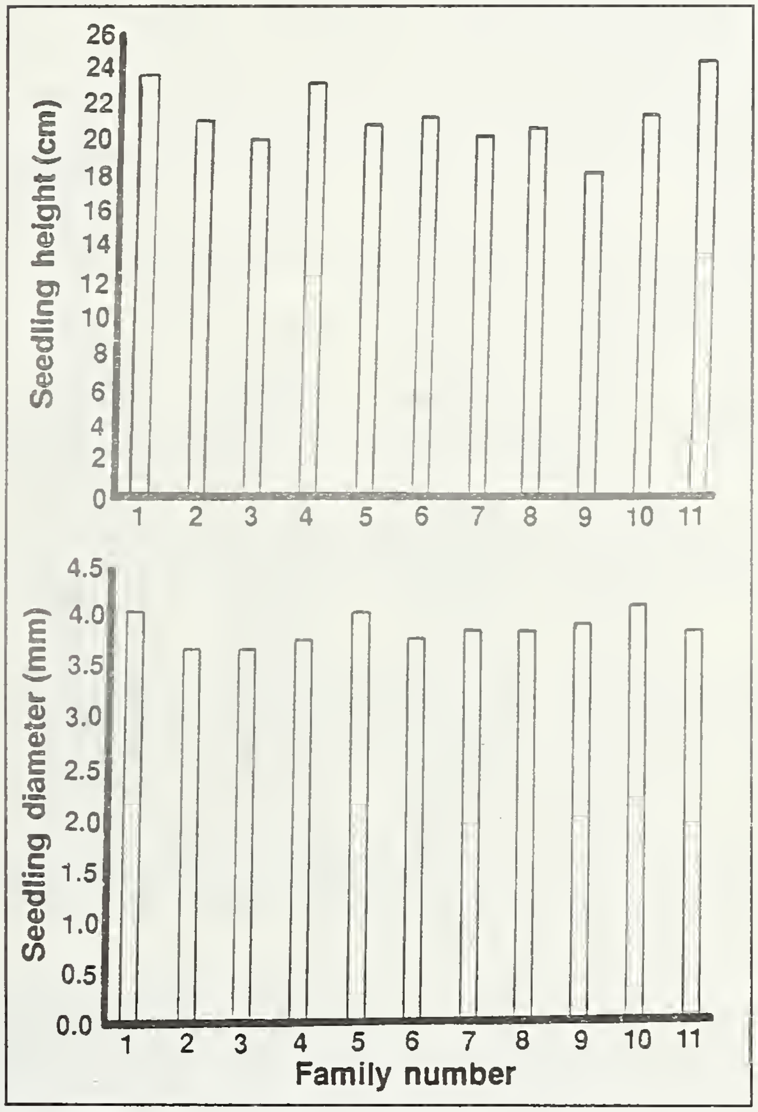

Figure 2—Height and diameter of western hemlock seedlings just before treatment.

Seedlings grew well after treatment. For all families and fertilization treatments, seedlings grew by 102 percent in height and 73 percent in diameter by the end of the growing season. At harvest, there were significant differences among families in height, diameter, and dry weights of shoots and roots (table 4). Tallest seedlings were those of families 11, 1, and 4; the shortest were seedlings of families 8 and 9 (fig. 3). Seedlings of families 1, 4, 5, and 10 had the largest diameter. Shoot and root dry weights were highest in seedlings of families 1, 11, and 6. Overall, seedlings of families 1 and 11 seemed superior to those of other families. Parents of these two families occurred at lower elevations than did the other parent trees (table 1). For all fertilization treatments, there was a significant negative correlation (r = –0.78) between seedling dry weights and site elevation of parent trees.

Table 4—Family effects on growth characteristics of western hemlock seedlings[a]

Family	Final height	Height growth	Final diameter	Diameter growth	Shoot dry weight	Root dry weight
	Centimeters		*Millimeters*		*Grams*	
1	46.5 ab	22.9 ab	7.3 a	3.2 a	13.7 a	10.2 abc
2	43.2 bcd	22.2 abc	6.3 c	2.6 bc	10.6 cd	9.8 abc
3	42.6 bcd	22.7 abc	6.6 bc	3.9 ab	11.4 bcd	8.9 c
4	44.4 abc	21.4 abc	6.7 bc	2.9 abc	11.1 bcd	9.3 bc
5	42.3 bcd	21.6 abc	6.9 ab	2.9 abc	11.0 bcd	9.6 abc
6	42.8 bcd	21.7 abc	6.6 bc	2.8 abc	12.1 abc	10.7 ab
7	41.2 cd	21.1 abc	6.3 c	2.5 bc	10.0 d	9.0 c
8	39.3 cd	18.7 c	6.5 bc	2.7 bc	10.4 cd	8.7 c
9	38.4 d	20.3 bc	6.3 c	2.5 c	11.5 bcd	9.1 abc
10	42.9 bcd	21.7 abc	6.7 abc	2.7 bc	11.7 abcd	9.9 abc
11	49.1 a	24.9 a	6.3 c	2.6 bc	12.7 ab	11.0 a

[a] Values are averages of 3 fertilization treatments each, and individual treatments consist of 3 replications of 3 seedlings each. Averages in the same column followed by the same letter(s) are not significantly different at P<0.05.

Figure 3—Unfertilized western hemlock seedlings of families 9 (left) and 11 (right) (July 1980).

Table 5—Effect of nitrogen fertilizer on nutrients of oven-dried shoots of western hemlock seedlings[a]

Fertilization treatment	Nutrient					
	N	P	K	Ca	Mg	S
	Concentration					
	Percent					
0 kg N/ha	0.46 a	0.09 a	0.66 a	0.37 a	0.12 a	0.06 a
50 kg N/ha	.72 b	.07 b	.53 b	.38 a	.11 b	.06 a
100 kg N/ha	1.13 c	.08 c	.55 b	.46 b	.11 b	.07 b
	Content					
	Milligrams per shoot					
0 kg N/ha	35.8 a	7.4 a	52.0 a	29.0 a	9.0 a	4.4 a
50 kg N/ha	94.2 b	9.4 b	69.4 b	50.9 b	14.4 b	7.9 b
100 kg N/ha	147.7 c	11.1 c	72.3 b	60.8 c	14.8 b	8.6 c

[a] Values are averages of 11 families each, and individual families were represented by 3 replications of 3 seedlings each. Within the "concentration" and "content" sections, averages in the same column followed by the same letter are not significantly different at $P<0.05$.

Fertilizer Effects on Shoot Nutrients

For all families, the N fertilizer, at one or both rates of application, significantly affected concentration and content of all macronutrients determined in seedling shoots (table 5). The rates of 50 and 100 kg N/ha increased N concentration and content reflecting uptake of the N from the fertilizer and increased weight of seedlings. The increases were significantly higher at the higher rate of application. This was probably due to luxury consumption of N because the seedlings did not grow significantly more at 100 kg N/ha than at 50 kg N/ha (table 3).

Dilution by growth significantly reduced the concentration but not the content of P, K, and Mg. Fertilization, however, increased concentration and content of Ca and S at the higher rate of application. We have no explanation for this response.

Effects of Family on Shoot Nutrients

Concentrations and contents of all nutrients determined differed significantly among families (table 6). For all fertilization treatments, nutrient concentrations in the shoot ranged from 0.71 to 0.86 percent N, 0.07 to 0.09 percent P, 0.53 to 0.62 percent K, 0.38 to 0.46 percent Ca, 0.10 to 0.12 percent Mg, and 0.05 to 0.07 percent S. These values are lower than foliar concentrations of hemlock seedlings (Radwan and DeBell 1980) because of dilution with the wood and bark material of the shoot.

Contents of the various nutrients reflected differences among the families in nutrient concentrations and shoot dry weights. For most nutrients, content was relatively high in shoots of families 1, 10, and 11 and low in tissues of families 7 and 8. Families 1, 10, and 11 were among the highest in shoot dry weight, and families 7 and 8 had the lowest weights. Coincidently, parents of families 1, 10 and 11 occurred at much lower elevations than did parents of families 7 and 8.

Table 6—Family effects on nutrients of oven-dried shoots of western hemlock seedlings[a]

Family	N	P	K	Ca	Mg	S
			Nutrient			
			Concentration			
			Percent			
1	0.71 c	0.09 a	0.59 ab	0.38 c	0.10 c	0.06 b
2	.81 ab	.08 b	.56 ab	.46 a	.12 a	.06 b
3	.77 abc	.08 b	.61 a	.38 c	.11 b	.06 b
4	.86 a	.08 b	.60 ab	.44 ab	.11 b	.06 b
5	.81 ab	.09 a	.59 ab	.41 bc	.11 b	.06 b
6	.72 bc	.07 c	.62 a	.42 abc	.12 a	.06 b
7	.75 bc	.08 b	.58 ab	.40 bc	.10 c	.06 b
8	.77 abc	.08 b	.55 ab	.40 bc	.12 a	.06 b
9	.72 bc	.09 a	.53 b	.38 c	.12 a	.05 c
10	.80 abc	.09 a	.58 ab	.41 bc	.11 b	.07 a
11	.72 bc	.08 b	.55 ab	.40 bc	.10 c	.06 b
			Content			
			Milligrams per shoot			
1	100.1 a	11.4 a	76.8 a	51.9 a	13.7 ab	8.2 a
2	90.1 abc	8.6 bc	58.1 bc	49.6 ab	12.8 b	6.8 b
3	91.0 abc	8.7 bc	68.6 ab	43.2 cd	12.0 b	6.6 b
4	101.0 a	9.1 abc	65.9 abc	49.6 ab	12.4 b	6.8 b
5	94.4 ab	9.6 abc	64.7 abc	45.6 abcd	12.0 b	6.8 b
6	92.6 abc	8.4 bc	72.4 a	51.7 a	14.9 a	7.2 ab
7	79.9 c	7.9 c	56.4 bc	40.2 d	10.1 c	6.2 b
8	84.7 bc	8.4 bc	55.0 c	42.0 cd	12.8 b	6.3 b
9	89.2 abc	9.7 abc	58.2 bc	43.9 bcd	13.3 ab	6.2 b
10	100.2 a	10.6 ab	66.4 abc	48.2 abc	13.2 ab	7.9 ab
11	95.2 ab	9.9 abc	67.8 ab	50.0 ab	12.9 b	7.9 ab

[a] Values are averages of 3 fertilization treatments each, and individual treatments consisted of 3 replications of 3 seedlings each. Within the "concentration" and "content" sections, averages in the same column followed by the same letter(s) are not significantly different at $P<0.05$.

Growth Characteristics and Shoot Nutrient Relations

Positive and negative correlations were found between growth variables and shoot nutrients. Strongest correlations were with N (positive) and K (negative). As with K, all correlations with Mg were negative. For unfertilized seedlings, strongest correlations were between diameter and shoot weight, and Ca and Mg concentrations. These and all other correlations were negative and did not help explain the main results of the study.

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English Equivalents

1 hectare (ha) = 2.47 acres
1 millimeter (mm) = 0.039 inch
1 centimeter (cm) = 0.39 inch
1 liter (L) = 1.06 quarts
1 gram (g) = 0.03527 ounce
1 kilogram (kg) = 2.2046 pounds
$^{o}C = (^{o}F-32)/1.8$

Literature Cited

Bell, H.E.; Stettler, R.F.; Stonecypher, R.W. 1979. Family × fertilizer interaction in one-year-old Douglas-fir. Silvae Genetica. 28: 1-5.

Bray, Roger H.; Kurtz, L.T. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Science. 59: 39-45.

Bremner, J.M.; Mulvaney, C.S. 1982. Nitrogen-total. In: Page, A.L., ed. Methods of soil analysis. 2d ed., pt. 2. Agronomy. 9: 545-624.

Butters, B.; Chenery, E.M. 1959. A rapid method for the determination of total sulphur in soils and plants. Analyst. 84: 239-245.

Chapman, Homer D.; Pratt, Parker F. 1961. Methods of analysis for soils, plants, and waters. Berkeley, CA: University of California; Division of Agricultural Science. 309 p.

DeBell, D.S.; Silen, R.R.; Radwan, M.A.; Mandel, N.L. 1986. Effect of family and nitrogen fertilizer on growth and foliar nutrients of Douglas-fir seedlings. Forest Science. 32: 643-652.

Foster, G.S.; Lester, D.T. 1983. Fifth-year height variation in western hemlock open-pollinated families growing on four test sites. Canadian Journal of Forest Research. 13: 251-256.

Hoagland, D.R.; Arnon, D.I. 1950. The water-culture method of growing plants without soil. Circ. 347, Berkeley, CA: University of California. 32 p.

Jahromi, S.T.; Goddard, R.E.; Smith, W.H. 1976. Genotype × fertilizer interactions in slash pine: growth and nutrient relations. Forest Science. 22: 211-219.

Mallondo, S.M.; Krause, H.H. 1985. Genotype and soil fertility interaction in the growth of black spruce progeny from a central New Brunswick population. Canadian Journal of Forest Research. 15: 410-416.

Matziris, D.I.; Zobel, B.J. 1976. Effect of fertilization on growth and quality characteristics of loblolly pine. Forest Ecology and Management. 1: 21-30.

Perkin-Elmer Corporation. 1976. Analytical methods of atomic absorption spectrophotometry. Norwalk, CT: Perkin-Elmer Corp.

Radwan, M.A.; DeBell, D.S. 1980. Effect of different sources of fertilizer nitrogen on growth and nutrition of western hemlock seedlings. Res. Pap. PNW-346. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

Radwan, M.A.; DeBell, D.S. 1989. Effect of different urea fertilizers on soil and trees in a young thinned stand of western hemlock. Soil Science Society of America Journal. 53: 941-946.

Radwan, M.A.; DeBell, D.S.; Webster, S.R.; Gessel, S.P. 1984. Different nitrogen sources for fertilizing western hemlock in western Washington. Canadian Journal of Forest Research. 14: 155-162.

Rockwood, D.L.; Windsor, C.L.; Hodges, J.F. 1985. Response of slash pine progenies to fertilization. Southern Journal of Applied Forestry. 9: 37-40.

Snedecor, George W. 1961. Statistical methods applied to experiments in agriculture and biology. Ames, IA: Iowa State University Press. 534 p.

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